

# Case study-Sorghum Improvement in Zambia: Promotion of Sorghum Open Pollinated Varieties (SOPVs)

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**Abstract** — Food security has been a major concern because of low crop productivity in Zambia. Food insecurity is a cost to the social-economic development of Zambia and the SADC region. Unpredictable weather and climatic fluctuations have further aggravated this situation. To help address these challenges associated with climate change and crop productivity there has been a major paradigm shift towards crop diversification. As a result, the major goal of the Sorghum Breeding Program is to shift sorghum from a subsistence crop to a value-added cash crop. The inherent capacity of sorghum to tolerant harsh weather gives it an added advantage in mitigating the effects of climate change. The major goal of the Sorghum Program in Zambia is to upscale dissemination of already developed, underutilized, low cost, proven and improved sorghum technologies.

The program has invested in the development of Sorghum Open Pollinated Variety (SOPVs) Technologies that are high yielding with a broader environmental adaptation. SOPVs contribute to national food security and economic development and need to be upscaled through research, extension and enabling policies. The Sorghum Breeding Program utilizes sustainable approaches to ensure that the climate adaptation technologies are utilized by farmers along the Zambezi and Luangwa river basins because these are areas mostly affected by the impact of climatic fluctuations. To make this approach sustainable the Sorghum Breeding Program incorporates agronomic practices such as conservation farming and other soil improvement technologies.

Since farmers not only need food security but also income for social-economic growth, the program equally makes efforts to link small-scale farmers to markets. Disseminating technologies on sorghum value addition is also on the priority list because sorghum can also be used in the food industry (healthy foods), feed industry (stock feed and silage), brewing industry (malt and beer) and energy industry (bio-fuels). The private sector has been persuaded to continue investing in agriculture through input supplies and value addition. While the public sector (government) has been encouraged to make appropriate policies that can enhance sustainable agriculture. The changing climates and economies require that food diversification, sustainable agriculture and proven technologies for climate change adaptation are encouraged.

**Index Terms** — Adaptation, climate, food security, sorghum.

## I. INTRODUCTION

### A. Adaptation to Climate, Food Security, Health, and Social Economics

In Zambia and the Southern African Development Community (SADC) Region, the Luangwa and Zambezi river basins (Agro-ecological Region-I) are particularly vulnerable

to harsh climatic conditions such as heat, drought, and floods. The same area is highly affected by ecosystem degradation such as soil erosion. Consequently, these conditions negatively affect food security and the social-economic wellbeing of communities in this region [1]. In order to contribute to mitigating the effects of climate change the Sorghum and Millets Improvement Program (SMIP), at the Zambia Agriculture Research Institute (ZARI), which is under the Ministry of Agriculture and Livestock (MAL) has been promoting the use of Sorghum Open Pollinated Varieties (SOPVs) (Fig. 1).

SMIP is commonly referred to as the Sorghum Program or Sorghum Breeding Program or Sorghum Improvement Program interchangeably. Sorghum is one of the crops that is resilient to vulnerable weather patterns and can tolerate drought, heat, and flooding [2]. Sorghum is an important crop for food, nutrition, social-economic wellbeing, and climate change adaptation. The carbohydrates in sorghum are important for fighting ailments such as diabetes and obesity [3]. Antioxidant properties found in grain sorghum have important health benefits for humans [27]. Therefore, by adding value to sorghum through processing and marketing the social-economic value of sorghum is being realized [4], [5].

### B. Conservation Farming

About one third of Zambian agricultural production is done in marginal areas of Agro-ecological Region-I. These areas are not very suitable for the seasonal production of crops such as maize and common beans because the area often experiences erratic rainfall. This region is characterized by high surface and soil temperatures, plus low and poorly distributed rainfall. The fertility of the soil is generally poor in most areas of Region-I. Sorghum is better adapted to these harsh environmental conditions because of its physiology and profuse rooting system. Comparatively, sorghum is more productive in marginal soils and harsh conditions than other crops. By incorporating conservation farming methods and stubble cropping to reduce soil erosion these marginal lands have remained productive. In these areas conventional farming practices contribute to soil erosion whereas the practice of conservation farming and stubble cropping with sorghum helps to reduce soil erosion. The proliferous rooting system for sorghum is especially suited for this method of soil conservation.

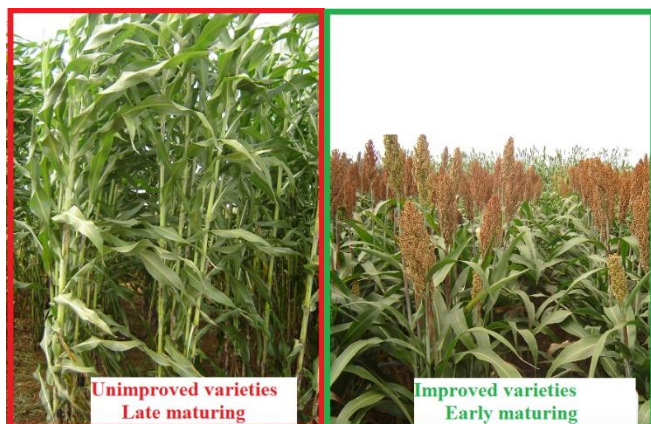


Fig. 1. Left: Unimproved late maturing photoperiod sensitive grain sorghum varieties taking seven months to mature. Right: Improved early maturing sorghums varieties taking only four months to harvest.

### C. Increased Productivity

The improved high yielding varieties have increased the productivity of sorghum per hectare under farmer conditions from 0.557 tons per hectare [6] to about 0.904 tons per hectare [7]. However, the potential yield under better managed farmer conditions is 4.5 tons per hectare [8]. Utilization of improved varieties also means that farmers do not have to clear extra land for farming. This has been extremely helpful in mitigating ecosystem degradation and climate change. The improvement of sorghum varieties through plant breeding has increased the crop productivity per unit area of land. The amount of land under production has not increased drastically partly because farmers are using improved varieties [7].

Precision agriculture and modern plant breeding has made it possible to produce more yield per hectare and hence freeing up marginal lands that are not suitable for agriculture. For example, the area under sorghum production has not increased since 2003, in fact it has been declining while production has remained steady at an average of 20,886 metric tons per annum (Fig. 2) in the major sorghum producing area (Fig. 5). However, productivity per hectare has been increasing steadily though not at the desired rate from 0.411 tons per hectare in 2007 to 1.2 tons per hectare in 2015 (Fig. 3) because of using improved sorghum varieties. Improved sorghum productivity has helped to reduce the amount of virgin land being cleared for crop production. This has helped to restore more natural ecosystems and has helped to mitigate detrimental effects of climate change. The ever-increasing population pressure from 12.4 million in 2008, 14.4 million in 2012 [9] and 17.9 million in 2019 [10] cannot be sustained without using high yielding climate smart crops. It is therefore imperative that proven agriculture technologies for sustaining food production be upscaled.

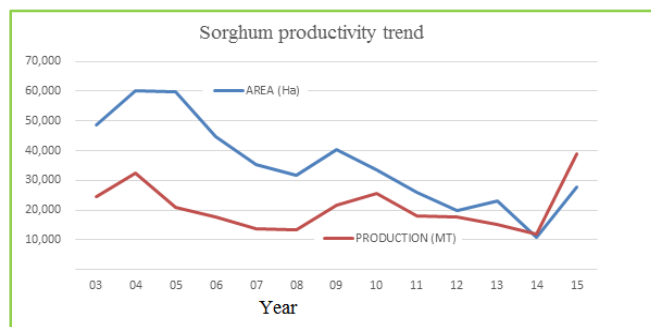


Fig. 2. Area under sorghum production has been decreasing while production has been fluctuating steadily between 15,000 and 30,000 (average 20,886) tons per annum. Source: Adapted from Solomon & Nicholas, 2013. An indicator that productivity or yield per hectare is going up due to utilization of improved varieties (see Fig. 3).

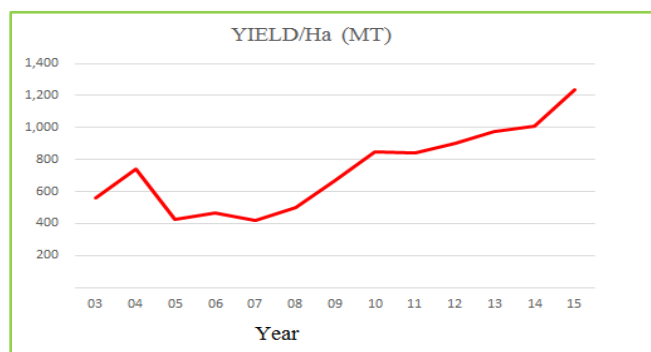


Fig. 3. Increasing productivity per hectare (average yield per hectare): Source: Adapted from Solomon & Nicholas, 2013. Even though production and area under production is going down, productivity or yield per hectare is going up due to utilization of improved varieties.

### D. Seed Systems

Since the early 1980's, a total of 16 improved sorghum varieties have been developed and released by the Sorghum Breeding Program at ZARI, but seed has not been readily available for sorghum. Seed companies are expected to be channels for production and distribution of these improved sorghum varieties to farmers. However, this sector has been reluctant to engage in seed production and marketing of sorghum, primarily out of concern for its low profitability and erratic seed demand for open pollinated sorghum varieties because they can be recycled [8]. The seed companies that were tasked to produce seed have failed to deliver seed to far flung areas citing high operational costs and poor returns on investments.

As a result, the sorghum program has adopted a seed systems model from Tanzania for open pollinated varieties that has been very successful [11]. The Sorghum Program engages seed companies formally and informally to encourage them to venture into seed production for a profit with the help of Seed Control and Certification Institute (SCCI). These seed companies include Kamano Seed Company and Indigenous Seed Company. Nevertheless, the program has not shunned away from encouraging big seed companies like Zamseed to use special models for seed delivery of SOPV sorghum seed to remote rural farmers. Interventions such as capacity building of decentralized seed dealers through training, improve linkages to sources of improved sorghum varieties, provision of adequate quantity and quality of foundation and certified seeds, provision of market information on improved varieties to the surrounding farmers and beyond has improved accessibility of improved

sorghum varieties and incentivizing sorghum production.

More than 9 metric tons of seed were produced and distributed by the Sorghum Breeding Program between 2009 and 2011 (Fig. 4). Mobilization of farmers to form cooperatives to be involved in the multiplication and marketing of seed at community continues to be revised and improved. Grain marketing companies such as Tupilwe Suppliers, Toyota Tsusho and Commodity Holdings Company (CHC) have not only helped to facilitate grain aggregation and marketing but also agriculture input distribution such as herbicides, fertilizers and sorghum seed. They have even gone a step further by assisting farmers with grain sorghum harvesting by providing combine harvesters at a low fixed rate.



Fig. 4. Reviving the cottage seed industry through the farmer served seed systems. Siavonga district, Lusitu village.

#### E. Value Addition

Were as long-ago industries worked in isolation to development value added products and services, nowadays the Sorghum Program is actively engaged with the sorghum processing industries to develop products and services. The companies working with the Sorghum Program include; (i) Zambia Breweries that is using grain sorghum in malt based beverages; (ii) Omega Foods that is milling white and red grain sorghum for human food; (iii) Sydney Bakery that is using grain sorghum in bread making and (vi) Tiger Animal Feeds that is using grain sorghum for poultry stock feed. These are not the only companies working with the Sorghum Program. There are many more such as Aller-Aqua and Kapiri Breweries.

Ten successful workshops have been held with companies to train extension staff and farmers on sorghum grain quality requirements by the industry. The same workshops also served as market linkages for sorghum growers to the industry. Through these trainings; farmers like Edward Mwelwa of Masaiti district on the Copperbelt province, Request Mulwani of Kalomo district, Adrian Bignell of Mazabuka district as well as farmers like Joe Makwenda, Watson Helenga, Friday Hambwelu, and Lewis Kagoma of Siavonga district have greatly benefited from technology dissemination [4]. Mulwani now boasts of producing over 10 hectares of sorghum with an annual production of over 17.5 metric tons while Mwelwa cultivated 22 hectares of sorghum and successfully subcontracted over 1000 farmers to grow sorghum for Kankonyo breweries which consumes about 300 metric tons of sorghum annually.

Market linkage initiatives have encouraged beverage industries to consume more sorghum and thus creating market opportunities for small-scale farmers. The increase in the number of companies using sorghum has been largely attributed to the efforts deliberately initiated by the Sorghum Program. Using the IPTA platform information sharing on nutrition, prices, demand, supply, and value chains is transforming the image of sorghum into an important crop.

#### F. Policies

Two policies have been particularly beneficial for sorghum production namely the Food Diversification Input Support (FoDiS) Policy which encourages growing a variety of crops for food security and climate change adaptation and the Farmer Input Support Program (FISP) that has included sorghum on its agenda. Better marketing and value chain policies are in the pipeline and it is important that when policies are made, they should benefit the farmers [22]. The sorghum program is recommending that more and better policies be put in place to encourage sustainable agriculture production. And such policies include giving better incentives for sorghum producers and the industries utilizing sorghum.

## II. OBJECTIVES

The general objective of this documentation is to highlight proven practices that enhance the ability of farmers to mitigate food insecurity, health & nutrition, environmental degradation, climate change, and social-economic wellbeing by utilizing SOPVs. The specific objectives include informing policy makers on the importance of these tools in alleviating food and nutrition security. The idea is that this document will also help to shape policies that help to address important issues on climate change adaptation and agriculture productivity. Changes in consumer preferences and social-economic developments in the past decade have necessitated a reorientation of SMIP. The program has been realigned to address some of these pressing challenges.

For SMIP to remain relevant in the current situation significant shifts in the sorghum research objectives have been made. The importance of specific research objectives varies from one Agro-ecological Region to another. However, some fundamental objectives must remain the same for sorghum improvement, and these are; (i) adaptation to the target environment, (ii) high yielding, (iii) yield stability in production and across years and (iv) tolerance to abiotic and biotic stresses that may occur in the target area.

There is a high variability in the product targets for grain required by the producers and consumers, and these have necessitated a major shift in the research objectives of the Sorghum Breeding Program. As a result, research objective for producers and consumers have been aligned according to the requirements of each producer or consumer. The program is now focusing on the following research objectives:

#### A. Develop Sorghum Germplasm with the Ability to Cope with Biotic and Abiotic Stress

All sorghum germplasm developed by the breeding program must have a good ability to cope with major pests (fall army worm, stalk borers, crickets, shoot-flies, midge &



sugarcane aphid) and diseases (grain mold & anthracnose). On the other hand, the sorghum must be capable of growing optimally with reduced fertilizer rates to reduce the cost of farming. Reduced chemical pesticide use is another concern of health-conscious consumers. More importantly small-scale farmers are usually resource poor and chemicals add to the cost of production. Breeding for tolerance to drought and soil acidity are major concerns in Region-I and III respectively.

#### *B. Develop Sorghum Germplasm that is Adapted to the Changing Weather Conditions*

Region-I of Zambia is particularly vulnerable to either drought or floods, late rains, and poor rain distribution. The frequency of these detrimental events is becoming high due to climate change. This has serious consequences on food security. Varieties and hybrids are needed that can cope with these severe weather patterns. All released germplasm for Region-I needs to have these adaptive capacities in them.

#### *C. Develop Sorghum Adapted to Agro-Ecological Regions I, II, and III*

Zambia is divided into three Agro-ecological Regions based on rainfall patterns [12]. Region-I is in the southern areas of Southern and Western Provinces and the Luangwa valley of Eastern Province. It receives less than 800 mm of rainfall annually. Region-II with the highest agricultural activity, is the central plateau of Eastern, Lusaka, Central and part of Southern and Western Provinces, with an annual rainfall of 800 to 1000 mm. Region-III, mostly occupied by acid soils, covers large areas of Northern, Muchinga, Luapula, North-Western and Copperbelt Provinces. It receives above 1000 mm of rainfall per annum. New sorghum varieties and hybrids with targeted traits must either be bred for specific adaptation or wider adaption to all three regions.

#### *D. Develop Grain Sorghum Germplasm that is Suitable for Human Food and Nutrition*

The rising numbers of people with non-communicable diseases such as hypertension, diabetes and obesity has seen a rise in demand for sorghum with properties capable of combating these ailments. The type of sorghum needed should be drought tolerant, requiring low inputs and must have good milling properties. The grain should be high in polyphenolic compounds that are beneficial for people with such ailments. In addition, sorghum diets can reduce micronutrient deficiencies of iron and zinc which currently stands at 54% of Children under the age of five years [13]. This will complement the governments intervention measures on food fortification with important mineral elements for children. The yield for this type of sorghum under low input conditions must be 3 tons per hectare and 5 tons per hectare under good management practices.

#### *E. Develop Grain Sorghum Germplasm that is Suitable for Animal Feed and Nutrition*

In recent times there has been a constant demand for grain sorghums that can be used to make stock feed for cattle, goats, sheep, poultry, and fish. The sorghum breeding program needs to develop grain sorghum varieties and hybrids capable of meeting the demands of the stock feed industry. The grain sorghum must be drought tolerant, requiring low inputs and must have the nutritional content required by the industry.

Ideally the chemical composition must be close to maize to make them suitable for stock feed diets. The yield must be at least 3 tons per hectare under low input conditions and 5 tons per hectare under good agronomic practices.

#### *F. Develop Silage/Forage Sorghum Germplasm that is Suitable for Animal Feed and Nutrition*

Most farmers who have farm grazing animals also want to supplement their dairy (cattle & goats) and meat animals (cattle, goats & sheep) with silage/forage sorghums. The type of sorghum needed for this usage must be adaptable to climate change, and fluctuating weather patterns and must also have nutritious, sweet, juicy stalks with high digestibility. The yield must be 60, 000 tons per hectare under low input conditions and 100, 000 tons per hectare under good management conditions.

#### *G. Develop Sorghum Varieties and Hybrids Suitable for the Malting Industries*

The malt-based industries require sorghum suitable for both alcoholic and non-alcoholic beverages. The clear beer industries require a drought tolerant tannin free white sorghum grain requiring low agricultural inputs. The grain must have 36.0 Diastatic Units (DU) a measure of the fermentation capacity of grain. The yield under low input conditions must be at least 1.6 tons per hectare. The opaque beer industries also require a similar type of sorghum. On the other hand, flavor is a major requirement for the non-alcoholic beverages.

### III. GEOGRAPHICAL AREA

The geographical coverage for the promotion of SOPV technologies is along the Zambezi and Luangwa river basin in Agro-ecological Region-I of Zambia. This area is characterized by frequent droughts, heat, erratic rainfall, and flash floods. The area covers Eastern, Lusaka, Southern and Western provinces of Zambia and includes nine (9) districts in the project area and two (2) districts outside the project area (figure 6). The nine districts in the project area are Mambwe, Petauke, Luangwa, Rufunsa, Chongwe, Chirundu, Siavonga, Sinazongwe and Sesheke districts. Siavonga and Chirundu district before 2013 were one district called Siavonga but have since been split into two. The two districts outside the project area are Masaiti and Milenge in Agro-ecological Region-III which is characterized by high rainfall, soil leaching and soil acidity.

A total number of fifty-one (51) villages have participated in the utilization of SOPVs by district as follows: (1) Mambwe district; Masumba 1, Masumba 2, Ncheka, Jumbe, Kampasa and Mpomwa villages. (2) Petauke district; Matambazi, Nyamtuma, Njanje 1, Njanje 2, Chataika, Wankara, Mwanika and Mawanda villages. (3) Luangwa district; Kaunga A, Kaunga B, Chitope and Lunya villages. (4) Rufunsa district; Lunsemfwa, Shikabeta and Lubalashi and Mpasha villages. (5) Chongwe district; Kanakatampa and Chalimbana villages. (6) Chirundu District; Kapululila and Kabanana villages. (7) Siavonga district; Lusitu, Siangwemu, Lakeshore, Changa, Lusitu Bridge, Kayuni, Subcentre, Sikongo, Gwena, Simamba, Nabutezi and Bbakasa villages. (8) Sinazongwe district; Sinzala, Kanchindu, Siameja,

Muziyo and Maamba villages. (9) Sesheke district; Lusinina, Lozamba, Mwandi, Lusu West, Kalobolelwa, Mwandi and Ngweze villages.



Fig. 5. The major sorghum producing area, Region-I, in a bold red boundary. This is also the geographical coverage of the case study (Agro-ecological Region-I). Source: Adapted from www.googlemaps.com.

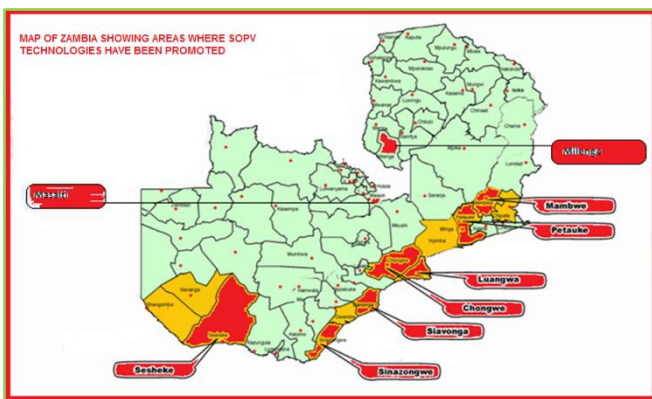


Fig. 6. Geographical coverage of the project area by district. Source: Lloyd, Mwila, and Medson, 2015. Districts from left to right: Masaiti, Sesheke, Sinazongwe, Siavonga, Chongwe, Luangwa, Petauke, Mambwe and Milenge.

#### IV. DEVELOPMENTAL PROCESS

Agricultural research in Zambia can be traced as far back as 1922 at the Experimental Gardens in Chilanga. Research was more focused on cash crops, such as cotton and tobacco. In 1953, the Department of Agriculture Research, Soils and Crops Research Branch was established with the headquarters at Mount Makulu Research Station. After Zambia gained independence from British rule in 1964, research focused more on solving problems for small-scale subsistence farmers. In the 1980s, research was reorganized to ensure that research activities were more tailored towards the problems of smallholder farmers. As early as the 1980s, the Crops and Soils Research Branch (CSRB) at Mount Makulu in Chilanga, Zambia, now called ZARI had recognized that sorghum is an important crop that can help mitigate food insecurity in marginal and dry land areas of Zambia because of its inherent capacity to resist drought and heat.

However, in the early days sorghum was only promoted as a subsistent crop by the Swedish International Development Agency (SIDA) and INTSORMIL [14] through a top-down research approach rather than participatory research [8]. It was not until 2010 that there was a strong desire to shift sorghum from a subsistent crop to a value-added cash crop because of modest adoption rates by farmers [15]. This

paradigm shift includes the deliberate promotion of sorghum for climate change adaptation because of the increased frequency of droughts in Region-I. To do all this, the program has been collaborating with the department of extension in the Ministry of Agriculture and collaborated with the Japanese International Cooperating Agency (JICA) through a project called Food Diversification Support Project (FoDiS) (2007-2011).

Much of the technical support for the project has been provided by the Sorghum Program. Other partners included the Forum for Agriculture Research in Africa (FARA) (2010-2014) under a project called Promotion of Science and Technology for Agriculture Development in Africa (PSTAD) with support from the Africa Development Bank (AfDB). Additional collaboration included the International Sorghum and Millets and other Grains Research (INTSORMIL) and the United States Agency for International Development (USAID) (2011-2012). The Agriculture Productivity Program for Southern Africa (APPSA) project and the United Nations Environmental Program (UNEP) were the recent partners in the dissemination of SOPVs for climate change adaptation (2014-2016 and 2014-2018 respectively).

The key difference between old methods and the new methods of extension is that the new method of extension involves the use of the Innovative Platform for Technology Adoption (IPTA). IPTA is a participatory developmental approach where significant use of new ideas and technologies are being done in ways that emphasize the collaborative and commercial use of ideas, technologies, and mechanisms to advance a pro-poor agenda. Because the Innovative Platform is a collective way to resolve common challenges it enables more goods or services to be produced with less effort or resources. The rapidly changing context of agricultural development considering climate change necessitated the re-orientation of goals and objectives and use of new approaches for economic development.

Since the paradigm shift market opportunities are opening for farmers in the project areas. The promotion of information dissemination and technologies on sorghum has resulted in several companies utilizing sorghum for making flour, silage, stock-feed, and malt (non-alcoholic & alcoholic beverages). In the capital city Lusaka, there is a flourishing business in the malting industry. Additionally, there are about 11 companies actively involved in processing sorghum into various value-added products (Table 1). Further, five grain marketing companies are now engaged in purchasing sorghum grain, namely Tupilwe Suppliers, Toyota Tsusho, Zambia Agriculture Marketing and Commodity Exchange (ZAMACE), CHC and Grain Traders Association of Zambia (GTAZ). Some “briefcase companies” as well as established companies are also engaged in sorghum grain marketing.

Unlike hybrids, SOPVs are low cost and have been improved to tolerate drought. They also have an added advantage because they can be recycled by the small-scale farmers. The seeds of these varieties can be recycled to a greater extent and maintain their genetic integrity. They can also be grown in much drier environments or in areas where rainfall is difficult to predict. The varieties can grow in much poorer soils and require little or no artificial fertilizers, but this does not mean fertilizer should not be used. Low input technologies for small-scale farmers in remote rural areas are

essential for sustainability because most farmers cannot afford agriculture inputs [8]. These technologies are not restricted to small-scale farmers alone, even commercial farmers are utilizing these low input technologies to get higher profits. These technologies use less water, fertilizer, pesticides, and they are productive even in harsh environments.

TABLE 1: COMPANIES INVOLVED IN SORGHUM VALUE CHAINS

Company	Sorghum-product	Product label
Zambia Breweries	Lager	Eagle
Kankoyo Breweries	Malt	Chibuku
Nkwazi Breweries	Malt	Nkwazi Beer
Tiger Animal Feeds	Stock-feed	Top Seed
Trade Kings	Beverages (non-alcoholic)	Maheu
Kapiri Breweries	Malt	Ubune
Kazungula Cooperative	Flour	Sorghum mill
Transcontinental	Stock-feed	Sorghum feed
One Banja (Banja1)	Flour	Sorghum mill
Omega Foods	Flour	Omega Flour
Sydney Bakery	Bread	Sorghum Bread

## V. TARGET BENEFICIARY GROUPS

The SOPV technologies were originally designed for resource poor but viable farmers in areas mostly affected by drought. Nonetheless, these technologies have spilled into non-target areas. An increase in the number of medium-scale and commercial farmers using these technologies has been observed. The involvement of processing companies helped to increase the utilization of sorghum for value added products. Many other direct and indirect beneficiaries are listed in Table 2. The implementation of this project was largely facilitated by SMIP, JICA, FARA and INTSORMIL in collaboration with the Department of Extension, Golden Valley Research Trust (GART), Care International and the Worldwide Fund for Nature (WWF). Partnerships with farmers, cooperatives, farmer training centers (Fig. 7) and the private sector and other government ministries like Ministry of Community Development and Social Services (MCDSS) were also part of this process.



Fig. 7. Training of camp extension personnel in Mambwe district. Masumba Farmer Training Centre.

TABLE 2: BENEFICIARIES OF THE SOPV TECHNOLOGIES

Target Beneficiaries	Female	Male
Direct Beneficiaries-Small-scale farmers project areas	530	525
Indirect Beneficiaries-Small-scale farmers project areas	265	260
Indirect Beneficiaries-Small-scale Farmers Non-Project Areas (Chongwe & Rufunsa)	150	150
Indirect Beneficiaries-Large Scale Farmers Non-Project Areas	0	4
Value Chain and Market Linkages-Direct Beneficiaries Sorghum Processing Companies	0	5
Value Chain Approach-Indirect Beneficiaries Sorghum Processing Companies	0	3
Networking and collaboration-Indirect Beneficiaries Sorghum Marketing Companies/Businesses	6	2
Training Workshops Direct Beneficiaries	14	130
<b>Total Beneficiaries</b>	<b>965</b>	<b>1079</b>

## VI. TECHNOLOGY ADOPTION

Because of the increased demand for sorghum by the beverage and stock feed industries since 2007, there has been a significant adoption of these technologies measured by the demand for seed in Region-I (Fig. 8). The widespread technology adoption resulted from direct and indirect intensive and extensive training of farmers and extension personnel. Participatory technology dissemination was very useful in this regard. Linking farmers to markets was especially useful for technology adoption because farmers saw the benefits of growing sorghum for incomes. In 2012, the total number of farmers growing sorghum nationally was estimated at 38, 820 which is about 2.74% of the farmers in the country [7].

For some industries to completely switch to sorghum approximately 165, 000 metric tons of sorghum need to be produced per annum. This implies that 10% of the farmers need to adopt growing sorghum and the productivity under farmer conditions will have to improve from 1.2 tons per hectare to at least 3.0 tons per hectare. To meet the potential demand for sorghum, there is need to promote the use of improved varieties and recommended agronomic practices [16] Improved varieties respond to improved management practices such as improved fertility and appropriate plant densities. In addition, alternate cropping and labor-saving cultivation systems under conservation agriculture have increased maize yields by more than 50% [17] these methods are similarly being utilized in sorghum technology adoption.

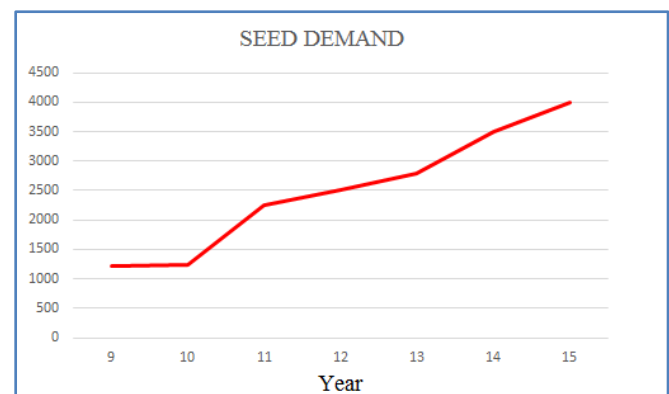


Fig. 8. Technology adoption by the quantity of seed (kilograms) demand in Region-I. This does not reflect the total demand which might be higher than these reported figures.



## VII. IMPACTS

### A. Adaptation to Climate Change

The improved SOPV technologies can produce reasonable yields if used properly. Farmers can get an average yield of about 4.5 tons per hectare under good management conditions and about 1.4 tons per hectare under harsh environmental conditions if the technologies are utilized properly. The average yield in Region-III is about 1.24 tons per hectare while in Region-II the average is about 1.1 tons while the lowest is Region-I with national averages ranging from 0.557 to 0.904 tons per hectare. Fortunately, this national average is steadily improving. Nevertheless, the potential yields under good management range from 2.0, 4.5 and 8.0 tons in Region III, I and II respectively.

One of the solutions to adaptation is to bridge the gap between the farmers yield and the potential yield. The ability of sorghum to produce even under harsh conditions has contributed to food security and increased income because of surplus sales. Farming communities that were often affected by food insecurities such as Luangwa, Rufunsa, and Sesheke districts have been able to enhance food security by utilizing such technologies. The initial number of targeted beneficiaries was 5, 000 in 2007. The number of farmers growing sorghum by 2012 stood at 38, 820 [7].

### B. Food Security

In Rufunsa district, in a village called Shikabeta farmers used to ask for relief food from the government nearly every year because of frequent droughts, the area lies on the leeward side of the Muchinga escarpment (mountains) and hence receives less rainfall [19]. But since the SOPVs were introduced no reports of food aid in that area have been reported since 2009 by the disaster management board [18]. In addition, some farmers can sale surplus grain to companies that are using it for malt-based beverages. This area is remote, and farmers do not have easy access to inputs like seed. The fact the SOPVs can be recycled has greatly alleviated the problem of sorghum seed in this area (Fig. 9). Availability of seed contributes to food security and this enhances technology adoption and adaptation.



Fig. 9. Left a dedicated sorghum farmer in Shikabeta village in Rufunsa district recycling sorghum seed in an area frequently affected by droughts.

### C. Productivity

Sorghum is a crop that farmers can grow with or without the addition of fertilizers (Fig. 10). When using fertilizer sorghum farmers only need half the amount of inputs for

unimproved photoperiod sensitive varieties of sorghum per hectare. 200 kgs basal fertilizer for improved varieties as compared to 400 kgs for unimproved varieties and 100 kgs top dressing fertilizer for improved varieties as compared to 200 kgs for unimproved varieties. Reduced input costs increase the profitability and productivity of sorghum.

Sorghum is a crop that can grow where other crops will not perform optimally. In fact, the farmers in the project areas rarely apply fertilizers but instead use minimal tillage (stubble tillage) and or conservation farming. The marginal lands that are easily prone to soil erosion with low soil fertility are thus prevented from degradation by using SOPVs and this helps to maintain the ecosystems and prevents over cultivation of land that may have serious consequences on the carrying capacity of the land. Consequently, the productivity of sorghum has increased by almost two-fold from 0.557 in 2002 to 0.904 in 2015 (national average).

Nonetheless, the current fertilizer cost is beyond reach of many small-scale farmers. Lower fertilizer application rates will further reduce the production cost of sorghum making it a more competitive and profitable crop. The cost of living is already a big issue in Zambia and the rest of the world. Therefore, reducing the production costs for sorghum will help to lower the cost of food in Zambia. Estimates show that an additional 1 billion tons of grain will be needed annually by 2025 worldwide. The estimated world demand for sorghum by 2025 is a staggering 100 million tons. That means sorghum productivity will have to increase further from 1.1 to 1.6 tons per hectare. As a result, sorghum productivity trials are already underway.

Additional efforts are under way to release dwarf sorghum varieties. Since dwarf grain sorghum varieties (genotypes) are more efficient at utilizing soil nitrogen [20], SMIP is accelerating the release of dwarf grain sorghums. Dwarf sorghums have traits with an added advantage of resiliency to weather extremes. The early maturing (60-90 days) dwarfs have a significant advantage over the current varieties that take 120 days. Dwarfs also have an advantage in commercial production because they can easily be harvested by combine harvesters. They are also advantageous to small-scale farmers because they require much less efforts to harvest (labor saving technology).



Fig. 10. Sorghum growing under conservation farming without chemical fertilizers in Rufunsa district, Mupashya village. Extension officer far right explaining the advantages of improved technologies.

#### D. Labor Saving Technologies and Gender Balance

Women and children are the ones usually given the task to do bird scaring in the field (Fig. 11). Farmers who are growing the improved red sorghum variety do not have to worry about this anymore. School going children no longer must disturb their school schedules and women have extra time to do other chores during the time when they are normally required to do bird scaring. This has helped to save labor for women and children. As a result, there are as many women as there are men participating in the technology adoption of improved technologies [21] the land use for sorghum production by women is like that of men. This seemingly simple but improved and appropriate technology has greatly benefited the farming community in this regard.



Fig. 11. Labour saving technologies for women and children, Ngweze village, Sesheke district. Bird tolerant varieties. Crop Husbandry Officer Josbin Muleya providing extension services.

#### E. Unplanned Positive Effects

In non-project areas, medium scale and commercial farmers have taken advantage of the production gaps left by small-scale farmers. Medium-scale farmers are thus immersing to supply the industrial grain required by the industries this is a good development for the social-economic wellbeing but may disadvantage the small-scale farmers who are the target beneficiaries.

Briefcase businessmen and women are also benefiting from trading in sorghum including small processing companies. One-Banja and Omega Foods are processing and marketing sorghum products in big chain stores (supermarkets) called Spar and Choppies respectively in Lusaka the capital city of Zambia. Sydney Bakery is also making and supplying sorghum bread in Lusaka, while others are using sorghum grain indirectly to produce oyster and button mushrooms [23].

Apart from farmers, extension personnel also benefited from trainings and capacity building. Institutions and non-governmental organizations also benefited in one way or another through collaborative projects. Sorghum technologies are contributing to the social-economic welfare of rural dwellers. It is fascinating to learn that some farmers have been able to build modern houses purely out of sorghum production [4], [21].

There are also some positive indicators that the number of seed companies now participating in grain sorghum seed production is rising steadily. Several seed companies are already supplying sorghum seed such as Zamseed, Seedco,

Klein Karoo, Kamano Seed, Indigenous Seed and Crop Serve.

#### VIII. VALIDATION

More than 200 farmers in Siavonga district were found using sorghum improved technologies for climate change adaptation, food security and social economic wellbeing in just one area called Lusitu [4]. In another study conducted by a student from Africa University in Zimbabwe to assess the extent to which the technologies are being adopted, in the same project area, 70% of all the farmers growing sorghum were found using improved technologies out of a population of 650 sorghum farmers [22]. The FARA validation process was done by Busani Bafana from Zimbabwe through structured interviews and desk studies in Lusitu district. While the second study was done by Joseph Musara a master's degree student also from Zimbabwe who had to relocate to Lusitu for more than a month collecting data on the marketing and utilization of sorghum in Zambia.

Other independent validations have been conducted by many entities including the National Agriculture Information Services (NAIS) and this resulted in the production of a documentary to validate that indeed a wide range of farmers are using these technologies for climate change adaptation in a bid to inform policy makers on the need for policy changes for climate change adaptation. The Indaba Policy Research Institute in collaboration with the Central Statistical Office (CSO) also produces national agricultural statistical information on sorghum and other crops. According to these publications 38, 914 tons of sorghum was produced by small-scale farmers [7].

Other validations included information collected from Zambia Breweries and CHC who confirmed that more than 4,500 farmers are actively engaged in producing and selling sorghum to CHC for Zambia Breweries. Over 2,500 metric tons are produced by these farmers [15]. Using participatory methodologies, improved varieties can produce four times more yield than the current national average of 0.904 tons per hectare [8].

#### IX. DRIVERS OF SUCCESS

In 2015 the total production of maize and sorghum was 2, 626, 344 metric tons. Of which less than one percent (0.31%) was sorghum [7]. For sorghum to effectively contribute to the National Gross Domestic Product (GDP) and social-economic development this figure needs to increase to about 3.1 %. Therefore, upscaling SOPVs is a driver of success in Region-I. Collaborative efforts have also been drivers of success for SOPVs. Collaboration was through public-private partnerships on value addition and market linkages attracted many farmers to produce sorghum for income generation and profits. Realizing incomes from sorghum means that farmers can improve their livelihoods.

Improved technologies contributed to the success because farmers could differentiate between improved and non-improved varieties in terms of yield and tolerance to biotic and abiotic stress. The release of the red sorghum variety by the Sorghum Program has helped to mitigate the effects of bird damage that is a major problem on smaller farms. The



bird tolerant varieties are also helping to save labor and hence contribute to the success of the sorghum agenda in the project area.

Other things that contributed to the success of the project was the government support and dedication of the sorghum team to promoting the SOPV technologies beyond the project area. Favorable agricultural policies played a key role in driving success. However, refinement of and additional policies biased towards sorghum production are needed. Sorghum has been included in the FISP, but this still needs to be realized fully. There is a strong recognition that there is need for major policy changes by the government to encourage the production and utilization of sorghum.

Challenges in the value chain still need to be addressed. Bulk buyers of sorghum require large tonnages. To satisfy the bulk buyers (industries) the productivity by small-scale farmers needs to increase from the current 0.904 tons per hectare to at least 1.4 tons per hectare and probably more commercial farmers need to grow sorghum. The production needs to increase from the current annual average of 20,600 metric tons in the sorghum producing areas to at least 1, 000, 000 metric tons in order for some companies to completely switch to using sorghum entirely for such things as stock-feed. The high yielding technologies are already available, but more farmers must adopt the SOPVs.

The physical infrastructure needs further improvements such as storage and roads to encourage agriculture investments in rural areas. Improvement of laboratories will enhance further development of technologies. A skilled workforce is available for upscaling these technologies from extension and research but training and information sharing still must be emphasized.

The high cost of financing agriculture loans and the associated poor credit culture of loan repayments by farmers may prevent further development of the sorghum industry. But could be investigated to facilitate further success of the industry. Inadequate processing facilities for other sorghum products could be increased. Pricing and marketing of sorghum grain still need further improvements.

Farmers in target project areas are an important factor in up scaling these technologies. The willingness or unwillingness of farmers to collaborate and participate in the implementation of planned activities is an important consideration. Hence the importance of incorporating the participatory innovation platform approach. The timely implementation of planned activities is highly dependent on timely availability of technical support and incentives.

The SOPVs have a regional relevance in addressing climate change adaptation, food and nutrition security agendas at national and regional levels including employment creation to achieve economic development. Mutual trust, teamwork, commitment, empathy, accountability, transparency, and interest in the proven technologies are also important ethical consideration for success.

## X. POTENTIAL FOR SCALING UP

There is a great potential for upscaling sorghum because the sorghum breeding program has already produced varieties such as Kuyuma for food, Sima a sweet sorghum variety for use as a multipurpose crop for silage, ethanol, and food. Apart

from that, a red sorghum variety called ZSV-36R was released at SCCI because it is preferred by the opaque beer brewers owing to its good flavor and better malting properties. ZSV-36R is also tolerant to birds under normal conditions [24] making it attractive for scaling up. There are also additional technologies that can be scaled out and these are; (i) Technologies on malting quality, red and brown types are being developed for better malting; (ii) Current research on the nutritional value of sorghum for human health and animal health is going on and the results will be useful for upscaling; (iii) The feed industry needs grains with a higher protein and nutritional quality. Enough germplasm for further improvement is already available in the breeding program; (iv) Research on sweet sorghum for silage and ethanol production have also begun to yield results needed for upscaling. Zambeef a company producing milk and beef products is now consuming over 12,000 tons of silage sorghum [25] and this number is projected to increase (Fig. 12).



Fig. 12. Use of sorghum in Silage and stockfeed by Zambeef (left) and Emman milling (right).

Other potentials for upscaling lie in the value addition and processing of sorghum into value added nutritious food products and a number of companies have been identified to help with the upscaling process and these are; (i) Zambia National Milling in Lusaka city, (ii) Choma Milling in Choma town, (iii) Antelope Milling in Luanshya, (iv) High Protein Foods in Lusaka, (v) Lumuno foods in Lusaka, (vi) Sylver catering in Lusaka and (vii) Emman Milling in Masaiti district; (viii) Copper-belt Energy Company (CEC) in Kitwe and (ix) Mukwa Breweries. The last two mentioned companies are already looking at prospects of producing ethanol gel for cooking and ethanol for blending with petrol and all these initiatives are likely to trigger the upscaling of sorghum production and consumption.



Fig. 13. Promotion of sorghum value addition in local economies, sorghum flour, Kazungula district.

The World Bank Agriculture Productivity Program for Southern Africa is also disseminating technologies for climate change mitigation [26] under a subproject called, “Promoting the adoption of improved management practices for increased sorghum production in Zambia”, and this is likely to trigger the upscaling of sorghum production. The technologies are not only being transferred to the farmers but also to the industry as well to add value to sorghum. In addition, the program also reproduced the sorghum production handbook initially published by the International Sorghum and Millets and Other Grains Research (INTSORMIL) and the United States Agency for International Development (USAID) and the book has been widely used by both extension workers and farmers. These initiatives by APPSA, INTSORMIL and USAID have regional spillover effects which CCARDESA helps to coordinate through collaboration.

The initiatives to shift sorghum from a subsistent crop to a value-added cash crop have yielded good results. The local demand for sorghum is slowly but steadily rising. Zambia Breweries in Lusaka is using 2,500 metric tons of grain per year for Eagle Lager and Chibuku (opaque beer) production (Fig. 14) and the consumption is projected to rise to 5,000 tons per annum. Kankoyo Breweries in Mufurila has increased consumption from 150 to 300 metric tons per year for opaque beer production. On the other hand, Mukwa Breweries in Lusaka is using around 36 tons. Most companies using malt are still importing from South Africa this implies that there is a need for upscaling. Chat and Lusaka Breweries in Lusaka city are using undisclosed amounts of sorghum but certainly significant amounts. Transcontinental a company in Siavonga town is using sorghum for stock feed production and consumes about 96 metric tons a year. Tiger Animal Feeds in Lusaka is utilizing sorghum for free range and caged poultry stock-feed under a brand called Top-seed. There are a few commercial farms that are beginning to tap into this market like the Kalomo sorghum farmer Request Mulwani and the Kazungula Sorghum Farmer's Cooperative growing sorghum for export to Zimbabwe and Botswana (Fig. 13). On the other hand Zambia has received numerous requests from a few countries to supply sorghum for example, Democratic Republic of Congo (Congo DR) (300,000 metric tons in 2011), Botswana (200,000 tons in 2009) and Kenya (99,000 metric tons in 2011) from Global Food Networking in 2012 and 2013. However, these quantities could not be met. In 2018, there was a further request to supply 12,000,000 metric tons of sorghum to China but still this demand could not be met These developments are good opportunities to increase sorghum production in Zambia.



Fig. 14. Sorghum value addition by the beverage industries.

## XI. SUSTAINABILITY

To ensure long-term sustainability of climate smart initiatives the country needs to adopt the value chain approach and market linkages to increase the demand for the grain and shift sorghum from a subsistent crop to a value-added cash crop. Processing and value addition will offer alternative uses for sorghum. Once the demand for sorghum grows there will be no need for certain deliberate actives in the technology transfer and farmer-market linkages will become self-sustaining.

In order to sustain funding for continued research on sorghum for climate change adaptation the sorghum program is considering the possibility of progressively commercializing some of its research products through seed companies such as new varieties and hybrids through collection of royalties and technology licensing. This will hopefully ensure that funds continue to flow for research and development and hence ensure continuity of technology development for climate change adaptation and mitigation.

The sorghum program also engages its scientific team to solicit for competitive research grants through high quality research proposals, lobby for government support and seeking new funding from development partners. In addition, the program creates linkages with the industry and the private sector for the purpose of funding research projects relevant to their areas of interest such as research on malting quality, biofuels, and perennial sorghums.

For the sorghum technologies to be widely adopted in a sustainable manner they should be demand driven and fit well within the existing or emerging farming systems. The technologies must be low cost and in line with both national and regional policies. Sustainability also means transferring technologies that can be easily adopted because many agricultural producers in Zambia, Mozambique and Malawi are resource poor. Therefore, low cost sustainable innovations stand a much better chance of being adopted and hence sustainability. As a result, cost effective technologies that fit well into the existing farming systems need to be prioritized.

To ensure availability of sorghum on the market providing sorghum market information is essential. To achieve this, the program enlists the support of organizations such as ZNFU, ZAMACE, CHC, NAIS, Extension and the Industry.

Long-term production of sorghum depends on how environmentally sustainable sorghum production will be. To do this the Sorghum Breeding Program continues to involve sustainable agricultural practices such as crop rotations with nitrogen fixing plants like soybeans, beans, and cowpeas. To maintain soil fertility manure and fertilizers need to be applied judiciously. Without these practices, soil fertility will diminish. Technologies in soil fertility management are therefore part of technology transfer.

The program makes deliberate efforts to ensure that technologies developed are gender sensitive to avoid disadvantaging the women and youths. Equal opportunities for men and women including youths to acquire new technologies are being created.

Regional linkages to enhance development of technologies ensures a sustainable use of resources. To accomplish this, the program seeks active involvement of regional research partners such as FARA, CCARDESA, COMESA and SADC



to make relevant regional policies that are useful for regional collaboration and development.

## XII. CONCLUSION

The contribution of sorghum to food security, climate change adaptation, and the economy cannot be overemphasized. Scientific research has shown that most of underutilized crop species like sorghum have a lot of nutritional value. Promoting sorghum as a food crop with health benefits and other important uses can easily find use in urban markets in a processed form and farmers could earn incomes from crop sales. Utilizing various varieties for different end users will also promote crop diversification. Farmers in Region-I need to grow crops that are more adaptable to the environment they live in because this will help improve food security. But somewhat not all farmers are able to attain higher yields due to several social-economic constraints and inadequate policies.

It is equally important to develop-the cottage seed industries by promoting small seed companies to produce seed in remote rural areas. Most seed companies are not willing to invest in seed for underutilized crop species in remote rural areas sighting high investment costs and low returns on their investments yet even remote rural farmers also require high quality planting materials. This can be partially resolved by assisting farmers to re-establish or develop their own local seed industry. The Zambian seed policies administered by SCCI clearly need to be refined to attract seed companies to go into seed production of underutilized crops that are essential for climate change adaptation.

The SMIP team (Fig. 15), shifted research objectives to address the prevailing, food & nutrition insecurity issues, environmental issues, and the social-economic situation. The team also emphasized the importance of sorghum in the economic development of Zambia and the SADC region. The value chain approach was a key driver of success in elevating sorghum to a commercial crop. Collaborating partners both in the private and government sector greatly helped to facilitate this dissemination of SOPVs.



Fig. 15. The SMIP team. From right to left: Dr. Lloyd Mbulwe Sorghum Breeder, Christo Kubata (GW), Owen Mwiinga (GW), Theresa Chola (GW), Chris Mumba (GW), Samilani Banda (GW). Not in the picture Sombo C. Musukuma (ARO), Asimbuyu M. Shawa (ARO), Cecilia Mbilishi (STRA), Moffatt Mhiti (TRA), Benson Kaoma (GW), and Henry Buumba (GW). GW=General worker, ARO=Agriculture Research Officer, STRA (Senior Technical Research Assistant), TRA=Technical Research Assistant.

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He is currently working on private public partnership projects with Anheuser-Busch International Beverages (ABInBev)/Zambia Breweries, Omega Foods, and other enterprises to develop new products from Sorghum. He has strong collaborative linkages on sorghum research with Texas A&M University in USA and Sementes in Brazil. Additionally, he also assists in delivering special lectures in Plant Breeding and Genetics when called upon by various universities in Zambia and abroad. Further, he helps to supervise graduate and undergraduate students doing biological sciences, plant sciences and agricultural sciences at various universities.

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